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Desiccant-Based Combined Systems: Integrated Active Desiccant Rooftop Hybrid System Development and Testing

Final Report
Phase 4

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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CHP	combined heating and power
DDC	direct digital controls
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
DX	direct expansion
ERV	energy recovery ventilation
HVAC	heating, ventilation, and air-conditioning
IADR	integrated active desiccant rooftop
R&D	research and development
RH	relative humidity
RTU	rooftop unit
VAV	variable air volume
UIC	University of Illinois at Chicago

ABSTRACT

This report summarizes the results of a research and development (R&D) program to design and optimize an active desiccant–vapor compression hybrid rooftop system. The primary objective was to combine the strengths of both technologies to produce a compact, high-performing, energy-efficient system that could accommodate any percentage of outdoor air and deliver essentially any required combination of temperature and humidity, or sensible heat ratio (SHR). In doing so, such a product would address the significant challenges imposed on the performance capabilities of conventional packaged rooftop equipment by standards 62 and 90.1 of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

The body of work completed as part of this program built upon previous R&D efforts supported by the U.S. Department of Energy and summarized by the Phase 3b report *Active Desiccant Dehumidification Module Integration with Rooftop Packaged HVAC Units* (Fischer and Sand 2002), in addition to Fischer, Hallstrom, and Sand 2000; Fischer 2000; and Fischer and Sand 2004.

All initial design objectives established for this development program were successfully achieved. The performance flexibility desired was accomplished by a down-sized active desiccant wheel that processes only a portion of the supply airflow, which is pre-conditioned by a novel vapor compression cycle. Variable-speed compressors are used to deliver the capacity control required by a system handling a high percentage of outdoor air. An integrated direct digital control system allows for control capabilities not generally offered by conventional packaged rooftop systems.

A 3000-cfm prototype system was constructed and tested in the SEMCO engineering test laboratory in Columbia, MO, and was found to operate in an energy-efficient fashion relative to more conventional systems. Most important, the system offered the capability to independently control the supply air temperature and humidity content to provide individual sensible and latent loads required by an occupied space without over-cooling and reheating air.

The product was developed using a housing construction similar to that of a conventional packaged rooftop unit. The resulting integrated active desiccant rooftop (IADR) is similar in size to a currently available conventional rooftop unit sized to provide an equivalent total cooling capacity. Unlike a conventional rooftop unit, the IADR can be operated as a dedicated outdoor air system processing 100% outdoor air, as well as a total conditioning system capable of handling any ratio of return air to outdoor air.

As part of this R&D program, a detailed investigation compared the first cost and operating cost of the IADR with costs for a conventional packaged approach for an office building located in Jefferson City, MO. The results of this comparison suggest that the IADR approach, once commercialized, could be cost-competitive with existing technology—exhibiting a one-year to two-year payback period—while simultaneously offering improved humidity control, indoor air quality, and energy efficiency.

1. INTRODUCTION: INTEGRATED ACTIVE DESICCANT ROOFTOP

The primary objective of this research and development (R&D) program was to design, produce, and test a totally integrated packaged heating, ventilation, and air-conditioning (HVAC) system that combines the strengths of both direct expansion (DX) refrigeration and active desiccant dehumidification technologies. By design, this system was intended to mirror conventional rooftop package systems as closely as possible with regard to size, layout, installation requirements, and installed first cost. However, the integrated desiccant system would also provide capabilities not possible with existing rooftop unit (RTU) technology, specifically, the ability to accommodate any percentage of outdoor air, deliver any sensible heat ratio needed by the space, deliver low-dewpoint air in an energy-efficient fashion, and use waste heat recovered from a localized power source (i.e., an internal combustion engine), thereby completing a cooling, heating, and power (CHP) system.

The final system design configuration was built upon findings and design schemes previously described in Fischer and Sand 2002. This report described how an active desiccant module could be effectively coupled with a standard packaged RTU to accommodate increased outdoor air fractions and low sensible heat ratios. As part of this earlier work (including laboratory testing), we determined that to take full advantage of the efficiency and performance benefits offered by this active desiccant hybrid approach, the refrigeration portion of the system would need to be enhanced for improved modulation and capacity control compared with current packaged equipment.

The two pilot installations discussed in Fischer and Sand 2004 supported these findings. It was found that the added cost associated with a fully integrated system would be largely offset by the reduction in field coordination, second roof penetration, ductwork modification, and controls integration associated with an RTU plus an active desiccant module. Based on feedback from the end users and design engineers, there is a strong preference for the single-box, integrated hybrid rooftop system described by this report.

1.1 Component Integration and Flow Schematic

The integrated active desiccant rooftop (IADR) uses a DX cooling coil coupled with a variable-speed compressor, inverter-driven condenser-side capacity control, and matched evaporator and condenser coils selected for processing larger outdoor air quantities (high latent capacity). As shown by Fig. 1, the air is first conditioned by this cooling coil and then delivered to the active desiccant wheel.

Since this air is cool and saturated, the effectiveness of the active desiccant wheel is very high, allowing for the use of moderate regeneration temperatures (typically 200ºF) and reduced regeneration airflow quantities. Since the purpose of the active desiccant wheel is to deliver very dry air, not to process the entire outdoor latent load (as with many previous active desiccant approaches), the desiccant wheel can be thinner (less deep) and/or use large corrugations (flutes) to meet the dehumidification load. This subtle enhancement is critical to overall energy efficiency because it allows the parasitic energy associated with the active desiccant section to be minimized. For example, this design approach requires only a ¾-horsepower motor to provide the regeneration airflow for a 25-ton IADR system. Likewise, the pressure loss across the supply side of the desiccant wheel is typically 0.3 in. water column (in. wg), less than the pressure loss associated with a partially loaded 30%-efficiency air filter.

With the IADR (see Fig. 1), only a fraction of the supply air flow passes through the active desiccant wheel. The remainder bypasses the desiccant wheel through a modulating damper controlled by the direct digital control (DDC) system. Modulation of the amount of bypass airflow enables the system to meet the specific supply conditions required by the occupied space.

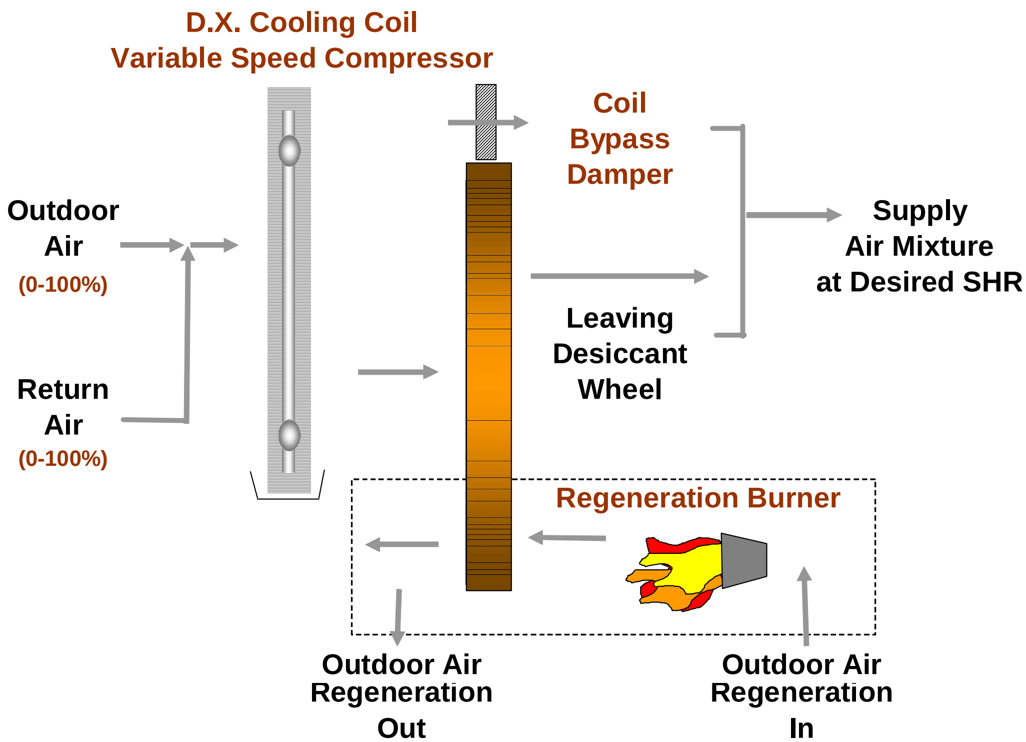


Fig. 1. Simplified flow schematic of the IADR system approach.

More details about the operation of the IADR approach, as well as an array of actual test conditions, are summarized in Fischer and Sand 2002.

The regeneration of the desiccant wheel located within the IADR system is accomplished with a direct-fired natural gas burner. The amount of regeneration energy delivered is modulated based on the space humidity setpoint and the supply-side humidity level to meet the latent load requirements. The system design can just as easily use hot water or steam from a CHP system for desiccant regeneration, for example.

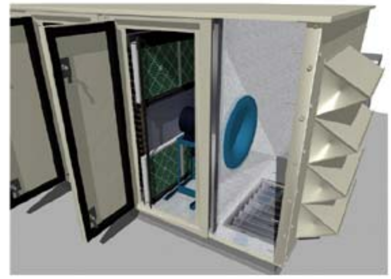
1.2 Final Production Prototype Description

One of the most challenging elements of this R&D program was packaging or integrating the active desiccant section and advanced refrigeration sections into a packaged system that resembled existing unitary equipment. Figure 2 is a rendering of the IADR rooftop system built and tested as part of this program.

As shown, the IADR can accommodate any percentage of outdoor or return air through the outdoor and return air section. The supply air is drawn into a direct-drive, backward-curve plenum fan, coupled with a frequency inverter to allow for air balancing and variable air volume (VAV) applications. Air is then passed through 30% filters and the cooling coil, through the active desiccant wheel or bypass damper, and then to the conditioned space. The supply air can be delivered from the bottom or side of the system, standard options offered for most packaged HVAC rooftop equipment.

The compressors are accessed from the supply side of the system. Each system has two compressors, one fed by a frequency inverter allowing for complete modulation throughout the entire refrigeration capacity range. An extended-capacity condenser coil is integral to the system, as are the condenser fans, which are either staged or operated at variable speed to provide the necessary capacity control.

Supply side of IADR showing outdoor air intake, filters, evaporative coil, active desiccant wheel, and integrated condensing section with variable-speed scroll compressors.



Outdoor air intake/return section with variable-speed supply air

Integrated active desiccant wheel

Fig. 2. Components viewed from the supply air side of the IADR system.

The cabinet construction used is similar to that offered by high-quality packaged unit manufacturers, and all of the access doors are removable to allow easy access to all components within the system.

Figure 3 shows a drawing of the regeneration side of the IADR system. This side of the system includes the entire regeneration section and required access. It includes the regeneration fan and motor, the dual gas burners, and the burner controls and all safety devices. This side of the system also includes two recessed electrical panels, one for high-voltage and one for low-voltage controls. The two hoods shown are for the regeneration air inlet and outlet.

Regeneration side of IADR showing burner section inlet and outlet, electrical and control panels as well as the condensing coils and fans

Outdoor intake section

Cut -away showing dual direct gas fired modulating burners

Fig. 3. Components viewed from the regeneration air side of the IADR system.

1.3 Application Options: DOAS or Total Conditioning, Energy Recovery

Another primary objective of the IADR product development program was to produce a final product that could serve as either a dedicated outdoor air system (DOAS) or a total conditioning system. Figures 4 and 5 provide graphic examples of these two application approaches.

Dedicated Outdoor Air System Mode

When applied as a DOAS (Fig. 4) the IADR system is typically sized to condition all of the outdoor air delivered to a facility or space. As a result, in the cooling mode, the outdoor air is dehumidified to a level that is dry enough to handle (1) the outdoor air latent load, (2) the humidity generated within the space by the occupants or by moisture-generating equipment, and (3) infiltration. In addition to handling the entire latent load, the IADR typically will handle the sensible load associated with the outdoor air. Therefore the preconditioned outdoor air is usually delivered at a temperature similar to that maintained within the occupied space but at a very low dewpoint.

Because the outdoor air volume is generally small relative to the total airflow volume required to cool the facility or space, the IADR system must deliver air at dewpoints much lower than those typically associated with conventional cooling systems. For example, a movie theater will typically require that the outdoor air be delivered at a 45ºF dewpoint to maintain the theater at approximately 50% relative humidity at peak occupancy conditions. A key advantage of the IADR system is that it can deliver air at a very low dewpoint with moderate temperatures leaving the coil, since the important "deep" dehumidification is accomplished by the active desiccant wheel.

Total Conditioning Mode

When applied in the total conditioning mode (Fig. 5) the IADR system delivers both outdoor air and recirculated air, in whatever proportions required by the occupied space. The capacity of the IADR system is sized to handle all of the sensible and latent loads associated with a space load, and the system has the unique capability to deliver the specific temperature and humidity necessary to maintain the desired space condition (variable sensible heat ratio).

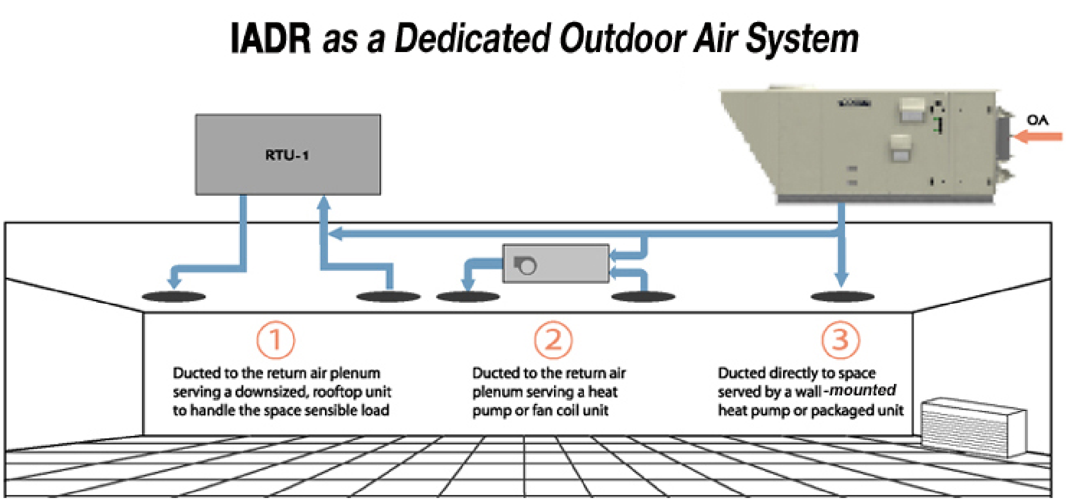


Fig. 4. Schematic example of the IADR applied as a dedicated outdoor air system.

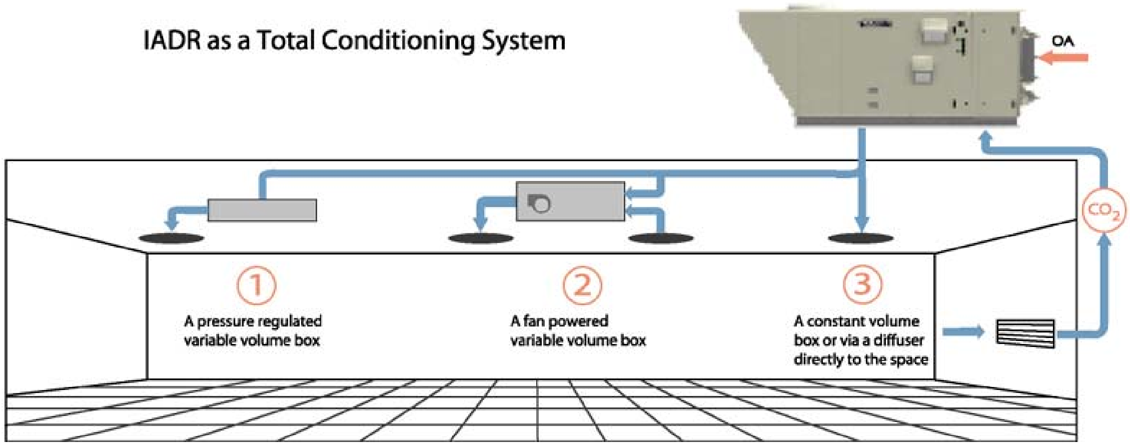


Fig. 5. Schematic example of the IADR applied as a total conditioning system.

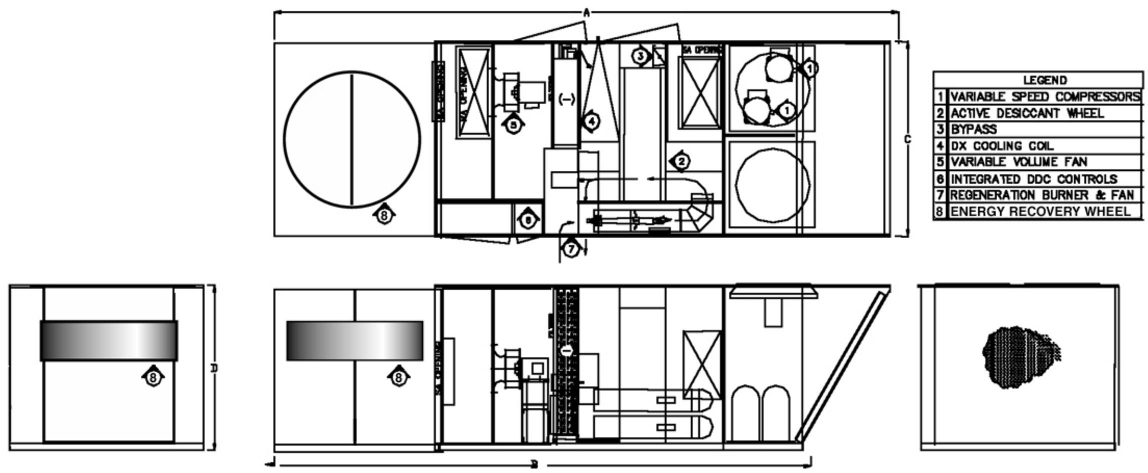
For example, a typical retail space may be designed to employ one IADR system to deliver all of the outdoor air needed within the space and to simultaneously condition, say, 40% of the facility. The system would deliver air dry enough that the remaining floor area could be conditioned with a very small conventional rooftop system, operated to handle primarily sensible cooling. A retail facility employing high-efficiency lighting, as called for by ASHRAE 90.1 (ASHRAE 2001), might require a supply air temperature of only 65ºF to handle the space sensible load. However, to maintain 50% relative humidity in the retail space, a supply air dewpoint of approximately 52ºF often is required. This is easily accommodated with the IADR.

The variable airflow capability associated with the IADR will also allow its use for demand-controlled ventilation, where appropriate, so that the amount of outdoor air delivered to the occupied space is modulated based on the indoor carbon dioxide level. When there is access to an exhaust air stream from the building, a total energy recovery unit (passive desiccant wheel) can be incorporated into the IADR (see Fig. 6) to significantly increase the overall operating efficiency.

1.4 Benefits Offered by the Technology

An earlier report discusses many of the benefits this hybrid IADR system approach offers. The following list summarizes the more important operational and performance benefits, most of which are discussed individually later in this report (Fischer and Sand 2002).

a. The integrated active desiccant RTU combines the strengths of advanced DX cooling technology (a variable-speed compressor) with the unique, low-dewpoint dehumidification capability offered by an active desiccant wheel.
b. This unit can deliver almost any combination of temperature and humidity level (variable sensible heat ratio) required by the occupied space while handling essentially 0 to 100% outdoor air.
c. The IADR approach uses the active desiccant wheel in its most energy-efficient range of operation, processing saturated air leaving the cooling coil to achieve very low dewpoints that are unattainable with conventional equipment.



MODEL NUMBER	DIMENSIONS (in.)				WEIGHT (LBS.)	NOMINAL AIRFLOW	MAXIMUM AIRFLOW	PERCENT OA (@ NOMINAL FLOW)	MAXIMUM TONS	SENSIBLE HEAT RATIO (SHR) RANGE	FV MODEL
	A	B	C	D							
ADM 2250	195	172	65	43	2550	2250	3600	0–100%	12.5	0–.75	FV2000
ADM 3000	208	182	75	55	3350	3000	4800	0–100%	17.5	0–.75	FV2000
ADM 3000	213	190	75	55	3800	3000	4800	0~100%	17.5	0~.75	FV3000
ADM 4500	237	195	80	71	4300	4500	7200	0~100%	25	0~.75	FV3000
ADM 4500	246	204	80	71	4450	4500	7200	0–100%	25	0–.75	FV5000
ADM 6000	266	206	90	74	5650	6000	9600	0~100%	30	0~.75	FV5000

Fig. 6. Initial general arrangement drawing for the IADR system, including an optional total energy recovery module.

d. In the IADR configuration, the desiccant wheel operates effectively with moderate regeneration temperatures (≈200°F), allowing the use of direct-fired gas or waste heat (e.g., from power generation/CHP).
e. This hybrid combination of vapor-compression and reactivated desiccant technology gives wide control flexibility. The bypass damper, cooling input (compressor speed), regeneration energy, and wheel speed can be modulated to provide almost any desired supply air temperature and/or moisture level.
f. The IADR can be applied as either a DOAS or as a total conditioning system. In either case, it can function as a true VAV system, varying the airflow across the evaporator coil.
g. This system delivers the precise cooling and dehumidification loads needed by the space, allowing designers to match the sensible and latent performance of the RTU to the actual load conditions. The result is effective temperature and humidity control at peak and part-load conditions.
h. Fewer tons of mechanical cooling capacity are required to achieve low supply air humidity conditions—up to 60% less cooling capacity compared with conventional systems.
i. The IADR system achieves lower space cooling costs. By effectively controlling space humidity at both peak and part-load conditions and allowing the space to operate with higher space thermostat settings, it significantly reduces operating costs.
j. An IADR unit uses gas for much of the dehumidification load. The cost of the energy used is greatly reduced during the cooling season by shifting much of the latent load from electrically driven vapor compression over to a lower-cost gas-regenerated active desiccant wheel (at traditional gas and electricity prices).
k. This hybrid system can provide true VAV operation. An advanced refrigeration system allows the flow across the evaporator coil to vary, allowing for significant fan horsepower savings and accommodating an unoccupied "dehumidification" mode of operation.
l. Improved indoor air quality is provided in the conditioned space. The composite active desiccant wheel acts as an effective gaseous phase filter that is constantly regenerated while it dehumidifies, providing a cleaner indoor environment than is possible with ventilation alone.

m. Smart controls are used. The integral DDCs adjust the conditions leaving the IADR to meet those needed by the space for the most energy-efficient operation that meets space comfort conditions.
n. The inherent trending capabilities can be used to document the performance of the system, including space humidity, energy consumption, ventilation effectiveness (carbon dioxide), and supply conditions.
o. The proposed system is easy to specify and easy to install. An IADR installs like all conventional RTUs and requires no more ductwork or additional power connections, critically important attributes for widespread market acceptance.

Integrating all of these benefits into one hybrid system presents not only engineering challenges but also obvious cost-control challenges. Currently available rooftop systems are extremely cost-effective because of mass production and limited performance targets. Developing a system that can deliver the necessary performance enhancements while maintaining a manufacturing cost structure that will allow it to be sold at an acceptable price presents the most significant challenge to this R&D program and new product introduction.

2. BACKGROUND

2.1 Market-Driven Need Based on Building Stock and Systems Selection

The market requirement for an integrated rooftop system that can accommodate the increased, continuous outdoor air quantities and humidity control recommended by ASHRAE 62 (ASHRAE 1999) cannot be fully appreciated without an understanding of the dominance of conventional packaged equipment within the U.S. HVAC market.

As shown by Fig. 7, more than 95% of all buildings in the United States have a total floor space of less than 100,000 ft^2. Of those buildings, approximately 90% use some type of packaged cooling equipment, predominantly packaged RTUs. As a result, the vast majority of energy consumed by the U.S. commercial HVAC industry (over 85% for cooling) can be attributed to packaged equipment.

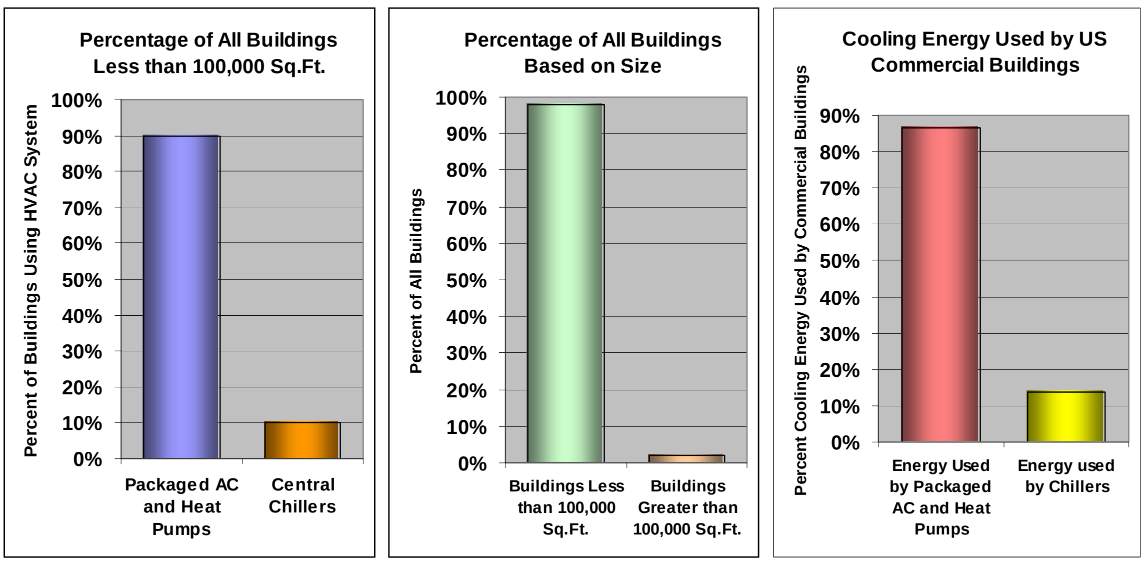


Fig 7. Data showing the predominance of packaged HVAC equipment. *Sources:* EIA 1999a, 1999b.

What is particularly problematic is that conventional packaged equipment is not capable (compared with chilled water, for example) of accommodating the increased, continuous outdoor air quantities now required by all major building codes (ASHRAE 62) without creating humidity control problems. This was well documented in the 2-year schools research program sponsored by the U.S. Department of Energy (DOE) and summarized by Fischer and Bayer (2003). It has also been widely discussed in the previous reports associated with this R&D program (Fischer and Sand 2002; Fischer and Sand 2004).

There are many reasons why conventional packaged cooling equipment cannot facilitate high percentages of outdoor air, especially in humid environments. Technical papers discussing the performance limitations of packaged cooling equipment with regard to humidity control have been presented by Henderson (1996), Khattar et al. (1985), and others. The equipment that is generally used to condition most buildings cannot deliver the outdoor air required to meet building codes without causing humidity control problems. One net result of this dilemma is that many buildings inspected during this program are being operated without any outdoor air so that humidity problems or, more specifically, comfort complains can be minimized.

During site inspections, including the 2-year schools investigation and five subsequent pilot site installations, nearly 70 conventional rooftop systems were checked to see if they were providing the outdoor air quantities required to comply with ASHRAE 62 (ASHRAE 1999). Not one was identified. More than 90% of these packaged systems were found to be operating with the outdoor air dampers closed. Upon investigation, it was found that in almost all cases the reason for closing these dampers was to achieve more comfortable interior conditions and satisfy occupant complaints, not to save energy.

Since it is clear that buildings should be constructed and operated in accordance with the building codes, strong support exists for a system that has the capability to deliver high percentages of outdoor air, continually and energy-efficiently, while simultaneously controlling space humidity.

2.2 Humidity Control Benefits: Comfort, Health, and Energy Impact

The importance of controlling humidity has been well established in medical journals, ASHRAE standards, and other numerous sources. Humidity control is linked to both comfort and health. Figure 8 summarizes how humidity levels impact the health of occupants in school facilities.

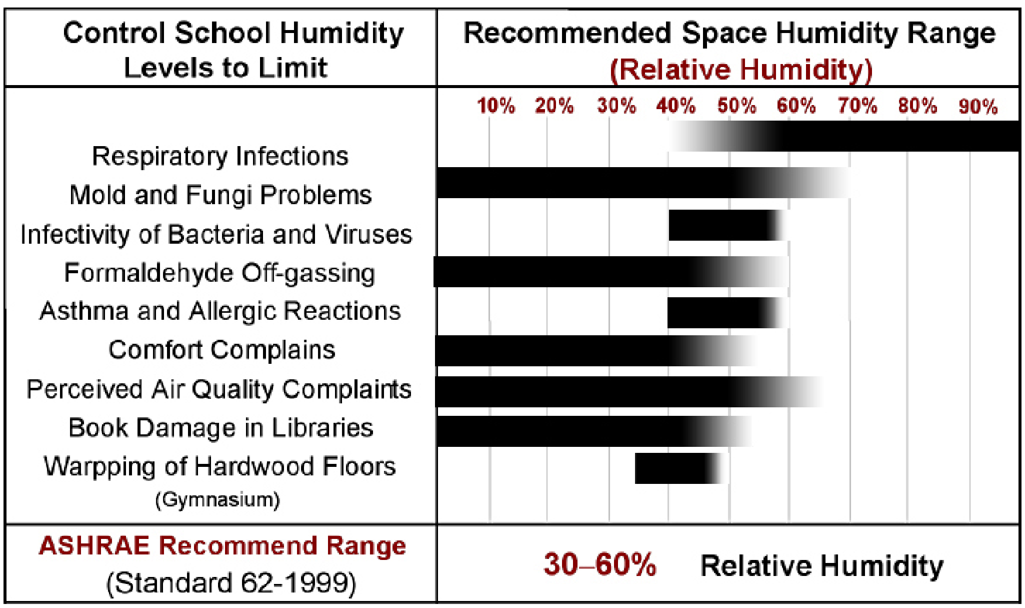


Fig. 8. Impact of humidity on various health and operational factors. Generally, the region between 40 and 60% humidity is the most favorable for human health and comfort and is less conducive to the growth of pathogens and to chemical interactions. *Source:* ASHRAE 1999.

However, the most recognized impact of humidity is comfort. The absolute humidity level (dewpoint) in the environment impacts the perspiration evaporation rate, which helps regulate the body's energy balance, skin moisture levels, and thermal sensations. An article in the *ASHRAE Journal* (Fischer and Bayer 2003) addresses the physiology behind perspiration and comfort, and chapter four of the ASHRAE *Humidity Control Design Guide* (Harriman et al. 2001) discusses the relationship between human comfort and humidity.

Harriman et al. (2001) references a 1998 *ASHRAE Journal* article (Berglund 1998) that suggests that as the humidity level in the space increases, occupants require a cooler indoor temperature to reach comfort. Figure 9 presents test data reported by Berglund (shown as green circles) that link humidity levels with a corresponding dry bulb temperature necessary to reach thermal acceptability for 80% and 90% of the adapted space occupants (20% and 10% dissatisfied) during the cooling

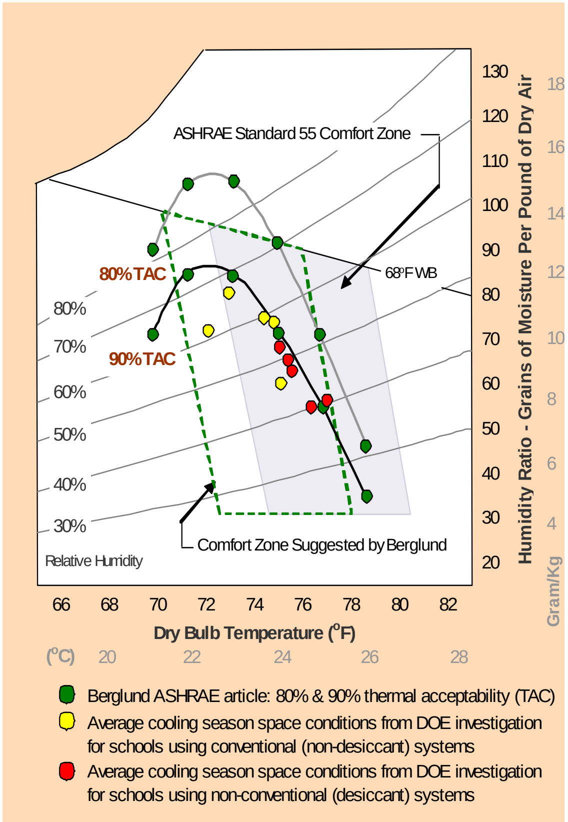


Fig. 9. Field test data collected in a major DOE-sponsored research program compared with the Berglund research (1998) that serves as the basis for ASHRAE Standard 55.

season. An 80% criterion for overall thermal acceptability serves as the basis for ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 1992).

A careful review of the temperature and humidity database resulting from the large DOE-sponsored schools investigation (Bayer, Crow, and Fischer 2000; Bayer et al. 2002) provided the data points shown in yellow and red in Figure 9. These data points show excellent agreement with the Berglund data, supporting the suggested relationship between a given humidity level and the temperature required to achieve a comfortable space condition. These data suggest that occupant comfort was reached at higher thermostat settings (warmer space temperatures) in the schools where humidity was controlled to a lower level. On average, the schools served by the non-conventional desiccant systems were maintained at a temperature that was 2°F (1.1°C) warmer (by occupant preference) than the schools served by conventional systems. The average space relative humidity was 12% lower in the humidity-controlled schools. The findings are particularly interesting because the occupants independently changed the only control point available to them, the space thermostat, to reach comfortable conditions. The data suggest that, given the choice, occupants will select thermostat settings to reach 90% thermal acceptability.

The findings from a pilot installation of an active desiccant module/RTU air-conditioner combination, the add-on predecessor to the IADR, were summarized in Fischer and Sand 2004. The restaurant site investigated was able to raise the thermostat setting by approximately 4 to 5°F (2 to 3°C) and maintain occupant comfort by reducing the space humidity from approximately 75% RH to 50% RH during the cooling season.

2.3 DOE 2.1 Modeling: Energy Impact of Lower Space Thermostat Settings

In addition to improving occupant comfort, the higher cooling-season thermostat settings made possible by controlling space humidity may result in significant energy savings. The DOE 2.1 program was used to model energy consumption in three typical building types, all using conventional HVAC equipment. Retail stores, schools, and restaurants were investigated as part of this program to determine the magnitude of potential cooling season energy savings.

Each facility was modeled to reflect typical operating hours, building construction, and outdoor air percentage. Three cities were chosen—Baltimore, Atlanta and Miami—to provide a range of weather patterns. A baseline cooling season thermostat temperature setting of 75°F was chosen for the analyses; and lower temperatures, down to 70°F in 1° increments, were used to show the corresponding percentage increase in energy consumption over the baseline value.

Figure 10 shows the results of these analyses graphically for the three building types and cities investigated.

Based on this analysis, it is evident that a significant reduction in cooling energy costs is associated with increased comfort at lower humidity levels, because building occupants are less likely to lower the thermostats. These findings should support decisions by building owners and designers to consider HAVC system designs that can meet ASHRAE 62 and control space humidity. Previously, the sole justification for improved humidity control has been to improve comfort or customer satisfaction or to avoid microbial problems. Based upon these analyses, it is clear that there is also a strong economic incentive.

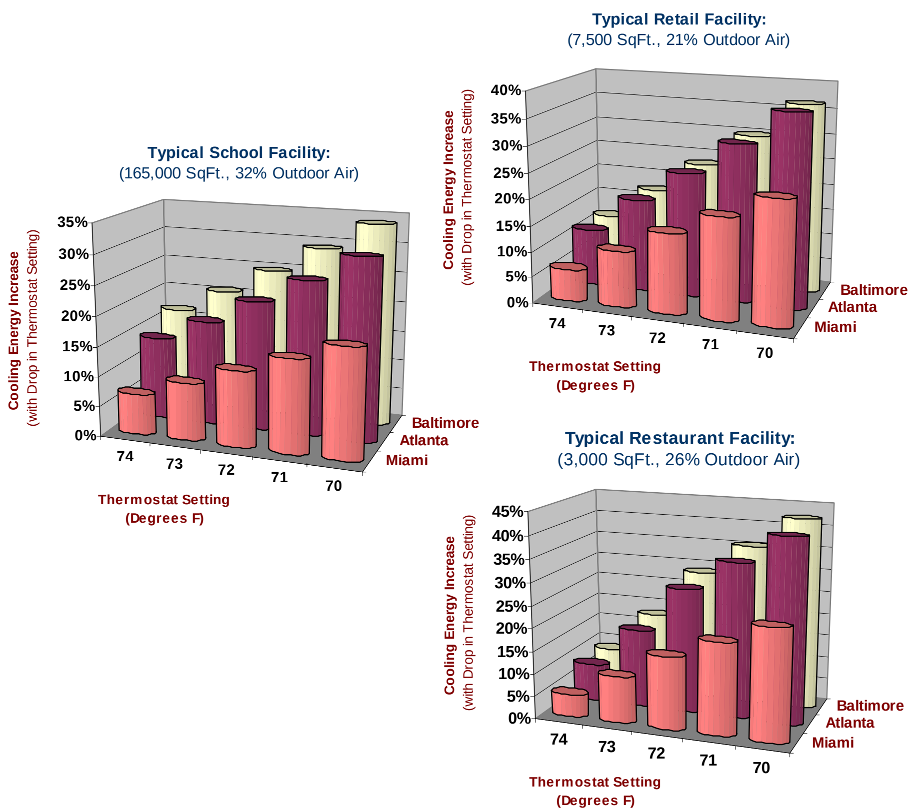


Fig. 10. DOE 2.1 modeling results for three building applications showing the energy increase associated with a decrease in thermostat setting as a response to higher space humidity.

3. CANDIDATE BUILDING ANALYSIS: GOVERNMENT OFFICE

3.1 Building Description

To determine the impact IADR equipment would have on mechanical design and building energy use, one of the key tasks included in this R&D program was to revisit a building that had been designed with conventional packaged equipment without humidity control. The specific areas of interest included cooling capacity requirements, electrical capacity needed, heating capacity requirements, approximate first-cost implications, and likely payback period.

C&M Engineering of Columbia, Missouri, completed the analysis using a three-story government office building located in Jefferson City, Missouri. The choice of an office building in a moderately humid location was intentional; the objective was to see if the IADR technology is applicable to buildings other than those with high outdoor air requirements in hot and humid climates. Figure 11 shows the building analyzed.

Fig. 11. The Jefferson City office building that was evaluated.

3.2 Equipment and Load Analysis

Given that the IADR is easily adapted to include a passive total energy recovery wheel as part of the integrated system, the analysis investigated two design alternatives in addition to the baseline, existing design. One alternative simply added a total energy recovery ventilation wheel to precondition the outdoor air to the existing packaged RTUs. The second alternative added an IADR system, installed as a DOAS system, that would handle all of the outdoor air required by the building and dehumidify it to a dewpoint capable of handling all of the latent load requirements. Table 1 summarizes the results of this analysis.

Table 1. Summary of building HVAC capacity requirements with and without the IADR

Packaged Rooftop Unit Schedule										
		Fan		Cooling coil		Burner input (MBtu/h)	Electrical			Min OA (cfm)
Approach	Size	cfm	hp	Total (MBtu/h)	Sensible (MBtu/h)		V	PH	MCA	
Base RTU	105 ton	32,550	50	1222	938	700	460	3	283	4000
Base w/ERV + RTU	90 ton	31,000	50	1051	876	490	460	3	262	4000
Desiccant hybrid w/ERV	60 ton	27,000	40	749	727	490	460	3	165	4000
Reduction from base	43%	17%	20%	39%	22%	30%			42%	

MCA = minimum circuit ampacity (amps) RTU = rooftop unit ERV = energy recovery ventilation OA = outside air

This investigation found that the installed cooling capacity was reduced by 43% from the existing baseline design. Approximately 14% of this reduction resulted from the integration of the passive energy recovery wheel, and the remaining 29% was associated with the IADR. These reductions are for an office building in a moderate climate bringing in 12% outdoor air.

As important, the IADR provided drier air that allowed control of space humidity with a diminished supply airflow compared with the baseline conventional system design. This 17% reduction in supply airflow resulted in a 20% reduction in fan horsepower.

The heating capacity was reduced and, in addition to the lower operating cost, much-needed building humidification was provided by the passive energy recovery wheel during the heating season.

Finally, the connected electrical load was reduced by 42% as a result of the lower cooling capacity and airflow requirements in the IADR plus ERV design. This impacts the cost of operation but also has a favorable impact on the installed cost because it reduces the cost of providing the necessary electrical service to the roof of the building.

3.3 Energy Analyses and IADR Market Price Determination

The results of this initial analysis were also used to establish a selling price target for the IADR system, thereby establishing manufacturing cost targets as well. It was assumed that if the IADR selling price would allow the owner of an office building to recognize a simple payback of one year, the IADR would be an obvious preference over more conventional options. By basing this analysis on an office building located in a moderate climate, the approach established a challenging, conservative sales price target.

Table 2 shows the results of this analysis. Considering all equipment, the IADR including the passive energy recovery module would have to sell for $37,400 in order to reach the targeted one-year payback for this specific application. Since the current market selling price for a total energy recovery module is approximately $2.75/cfm, and readily available refrigerant-based outdoor air preconditioning systems sell for $7 to 9/cfm in this size range, the target of $9.35/cfm for the combined IADR hybrid system appears to be appropriate and competitive.

At the target selling price, the office building modeled would recognize approximately $100,000 in net energy savings, in addition to fuel escalation savings, over a 20-year life cycle period. It would also provide improved humidity control during both the heating and cooling seasons and during unoccupied periods.

Table 2. Payback and market selling price projections for the IADR system

Packaged Rooftop Unit Schedule					
Approach	Package unit size	Package unit cost ($)	ER or hybrid cost ($)	Combined cost	Simple payback
Base RTU	105 ton	78,900	NA	78,900	NA
Base w/ERV + RTU	90 ton	72,400	11,000	83,400	1.5 years
Desiccant hybrid w/ERV	60 ton	46,500	37,400[a]	83,900[b]	1 year[c]
Reduction from base	43%	41%			

RTU = rooftop unit ERV = energy recovery ventilation

[a]Necessary selling price for a 4000-cfm active desiccant–total energy recovery hybrid based on assumptions.
[b]Combined sales price based on a 1-year payback and estimated savings of $5500/year for the active desiccant–total energy recovery hybrid system.
[c] Assumes payback of 1 year to determine necessary selling price.

4. CONTROLS: VARIABLE LATENT LOADS AND OUTDOOR AIR FRACTIONS

Of all the operational benefits offered by the IADR listed in Section 2.4, the two most important, relative to conventional packaged equipment, are the ability to handle large outdoor air fractions and the ability to deliver air at the specific temperature and humidity content necessary to reach the desired space conditions.

Having this capability is more important than ever, since it is now routinely required that buildings be designed and operated in accordance with ASHRAE 62. As a result, humidity control is becoming increasingly important to avoid mold and other microbial problems, especially in hot, humid climates. Finally, efficiency standards like ASHRAE 90.1 (ASHRAE 2001) present additional challenges to conventional packaged equipment with regard to latent capacity, and many equipment designers have yet to fully appreciate the challenges.

4.1 ASHRAE 90.1 Lighting Requirements

In the past, most buildings have been designed with lighting that uses approximately 3 to 4 watts per square foot of floor space. However, the ASHRAE 90.1 energy standard now recommends high-efficiency lighting that reduces power consumption to approximately 1.5 watts per square foot. Since lighting retrofits are easy to implement, many owners of existing buildings, often with the help of energy service contractors, are installing more efficient lighting.

This advantageous reduction of electrical consumption brings with it an often unanticipated challenge to the HVAC system—humidity control. Engineers who run load simulation programs for buildings will note that often a large portion of the sensible cooling load in a space comes from heat generated by lighting. This is especially true for offices and retail facilities. If more efficient lighting reduces this portion of the cooling load by 50%, as called for by ASHRAE 90.1, the sensible cooling will be significantly reduced while the latent load remains the same. As a result, compressors will run for shorter times, making it even more difficult for the HVAC equipment to control space humidity if the increased, continuous ventilation required by ASHRAE 62 is provided. In an effort to compensate for the increased latent load, RTUs in many newer buildings with lower lighting loads are being operated with the outdoor air dampers shut off. As was mentioned earlier, this practice was observed repeatedly when potential pilot sites were toured as part of this R&D program.

4.2 Equipment and Load Analysis for Various Commercial Buildings

Engineers who correctly model HVAC loads in buildings in order to size equipment are finding that the supply air conditions required to maintain the desired temperature and humidity control are both warmer and drier than in the past. This change is a result of increased lighting efficiency, the impact of the ASHRAE dewpoint design data, and the impact of the ASHRAE 62 ventilation requirements.

The information in Table 3 makes four primary points: (1) the impact of ASHRAE 62 and 90.1 on load calculations involving packaged equipment, (2) the requirement for equipment that can deliver independent temperature and humidity conditions to the space, (3) the need for equipment that can deliver air at lower dewpoints than are typically associated with conventional packaged equipment, and (4) the potential reduction in cooling capacity and associated efficiency improvements possible with the IADR systems.

Table 3. IADR versus conventional packaged equipment at ASHRAE design conditions

Application type	Outdoor air (%)	Supply conditions[a]		Tons required[b]		Increase
		Temperature (°F)	Humidity (grains)	IADR	Conventional	
School (elementary)[c]	34	64	57 (52°F dpt)	23	45	96%
Retail (pharmacy)[d]	22	65	59 (53°F dpt)	17	24	41%
Movie theater[d]	100	75	44 (45°F dpt)	31	52	68%
Restaurant[d]	49	64	56 (51°F dpt)	26	35	35%
Hotel[d]	100	75	52 (49°F dpt)	16	27	69%
Hospital (operating suites)[c, e]	50	59	47 (47°F dpt)	13	33	154%

Dpt = dewpoint

[a]Supply conditions necessary to maintain the space at 75°F/50% RH. Assumes outdoor design of 85°F/130 grains, typical building size and construction for each application, and high-efficiency lighting in accordance with ASHRAE 90.1.

[b]IADR is compared with a conventional cooling system sized to cool air to the required dewpoint; the energy required by the IADR is equal to or less than the reheat energy required by the conventional.

[c]Includes the addition of the total energy recovery modules since exhaust air path is generally available.

[d]IADR applied as a dedicated outdoor air system sized to handle all outdoor and space latent loads.

[e]Hospital example assumes a space condition of 68°F/50%RH. All others are assumed to be 75°F/50% RH.

Six building types were modeled to obtain the data presented in Table 3. Representative buildings were chosen as typical examples for each building type. ASHRAE 62 ventilation rates are used along with the ASHRAE 90.1 lighting requirements. Infiltration rates were determined using ASHRAE *Fundamentals* guidelines (ASHRAE 2001).

The supply air values, as noted in Table 3, reflect IADR operation in the total conditioning mode for the school, retail, restaurant and hospital. As shown, to meet the loads on a design day, the required dry bulb temperature and dewpoint temperature differ significantly. The IADR easily delivers these conditions. However, a conventional system must be operated so as to create very cold air temperatures leaving the coil, resulting in a low refrigeration efficiency. The conventional unit would then have to apply significant reheating (not allowed by ASHRAE 90.1) to reach the supply air temperature necessary to avoid over-cooling the space; this further reduces the efficiency of the system.

The movie theater and hotel in Table 3 are shown with the IADR applied as a DOAS. The supply air temperature shown as 75°F (23.9°C) was selected to represent a room-neutral condition. This temperature could easily have been 68 to 70°F (20 to 21°C), depending upon the selection of the down-sized conventional system handling the space sensible load.

4.3 Variable Sensible Heat Ratio Offered by IADR to Match Building Loads

To graphically demonstrate the ability of the IADR system to deliver air to the space at various combinations of temperature and humidity content (variable sensible heat ratios), performance modeling was completed by the University of Illinois at Chicago (UIC) as part of this program. Figure 12 is one of the data graphs resulting from this analysis. It shows the supply air temperature, humidity, and sensible heat ratio coming from an IADR as a function of the bypass fraction. As shown in Figure 1, changing the amount of air that bypasses the desiccant wheel alters the temperature and humidity supplied to the space. Figure 12 shows one leaving coil condition. By providing more or less capacity via an inverter-driven compressor, the system can easily provide conditions that are cooler or more dry than those shown.

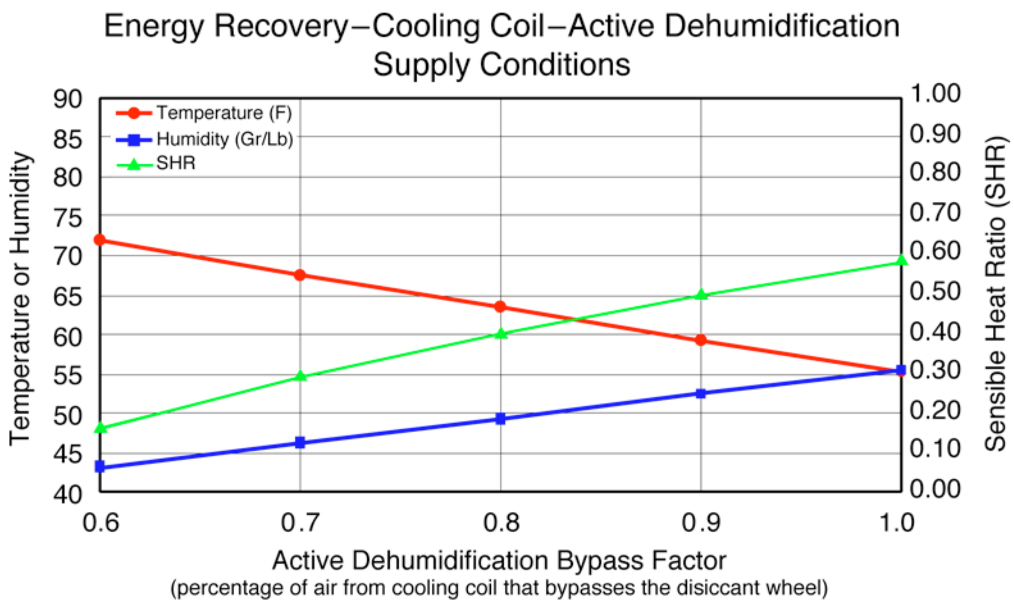


Fig. 12. The variable sensible heat ratios possible with the IADR at a single leaving coil condition and differing active desiccant wheel bypass setting. With the inverter-driven compressor, numerous leaving coil conditions are achieved.

As expected, less bypass air around the active desiccant wheel results in a supply air condition that is drier and warmer. More bypass results in cooler, less dry air. If the IADR system is delivering air that is cooler or drier than necessary, the variable-speed compressor can be modulated so that less cooling energy is consumed. If cooler or drier air is necessary, then the variable-speed compressor can be speeded up and more cooling delivered.

As a result, the system can efficiently deliver almost any condition required by the space at any point in time if the amount of bypass air around the active desiccant wheel and the amount of cooling capacity delivered via inverter-driven compressors and blowers are varied. Modulation of the regeneration energy and desiccant wheel speed, when appropriate, offer further flexibility.

5. SYSTEM DEVELOPMENT AND OPTIMIZATION

5.1 System Packaging to Emulate a Conventional Packaged Rooftop Unit

Given the ambitious selling price target set early in the R&D program and feedback provided by a marketing survey completed as part of Phase 1 of this project (Fischer, Hallstrom, and Sand 2000; Fischer 2000), it was clear that the IADR system needed to be packaged so that the final product had size, construction, installation, and specification characteristics similar to those of conventional packaged equipment.

This requirement presented a multitude of challenges. A panel construction needed to be designed and perfected to allow access to all components from the exterior of the system with a combination of removable panels and doors. The many high-value components used in this system—such as an integrated DDC system, multiple (up to 5) frequency inverters, high-volume/variable-speed condenser fans, extended surface evaporator and condenser coils, active desiccant wheel, and backward-curve plenum fan—needed to be selected, tested, and incorporated within the system while the cost of manufacturing was minimized. A novel direct-fired gas burner approach had to be developed that provides the needed desiccant regeneration performance but requires a fraction of the space and cost associated with more commonly used industrial burners.

Numerous design configurations and iterations were considered before a final system layout was reached that met the goals set by this R&D program. The regeneration side of the final design layout selected is shown in Fig. 13.

Figure 14 summarizes the final performance parameters and equipment subcomponent criteria for the IADR units that are anticipated to make up the initial product offering.

Fig. 13. SEMCO IADR system installed at a pilot site location.

IADR Technical Specifications				
Specifications	**IADR 2250**	**IADR 3000**	**IADR 4500**	**IADR 6000**
Airflow information				
Nominal supply airflow (cfm)	2250	3000	4500	6000
Max supply airflow (cfm)	3600	4800	7200	9600
Max outdoor airflow (cfm)	2250	3000	4500	6000
Cooling/dehumidification performance[a]				
Maximum supply flow with 30% outdoor air [b, c, d]				
Range of sensible cooling output (1000 Btu/h)	50–82	67–110	100–165	133–220
Range of latent cooling output (1000 Btu/h)	80–56	107–75	160–112	213–150
Range of sensible heat ratio	0.38 – 0.60	0.38 – 0.60	0.38 – 0.60	0.38 – 0.60
Supply humidity [e] (grains/dewpoint in °F)	51/49	51/49	51/49	51/49
Nominal supply flow with 30% outdoor air				
Range of sensible cooling output (1000 Btu/h)	34–70	46–95	68–140	90–185
Range of latent cooling output (1000 Btu/h)	73–58	97–77	145–115	195–155
Range of sensible heat ratio	0.32 – 0.55	0.32 – 0.55	0.32 – 0.55	0.32 – 0.55
Supply humidity [e] (grains/dewpoint in °F)	36/39.5	36/39.5	36/39.5	36/39.5
100% outdoor air [b, c, d]				
Range of sensible cooling output (1000 Btu/h)	34–76	46–101	68–151	91–201
Range of latent cooling output (1000 Btu/h)	110–75	147–100	220–150	293–200
Range of sensible heat ratio	0.24 – 0.50	0.24 – 0.50	0.24 – 0.50	0.24 – 0.50
Supply humidity [e] (grains/dewpoint in °F)	48/47	48/47	48/47	48/47
Maximum heating performance [f]				
Max heating capacity (Btu/h)	74,843	99,788	149,685	199,575
Compressor information				
Max (tons)	12.5	17.5	25	30
Minimum (tons)	10	15	20	25
Refrigerant used	R-22	R-22	R-22	R-22
Capacity control	Variable-speed compressor			
Regeneration information [g]				
Max regeneration airflow (cfm)	660	880	1320	1760
Max regeneration energy (Btu/h)	99,790	133,050	199,580	266,100
Fuel used	Direct-fired natural gas (option steam/hot water)			
Max regeneration temp (°F)	210	210	210	210
System information [h]				
Dimensions (L×W×H in.)	161×65×44	172×75×55	192×80×71	212×90×74
Weight (lb)	2000	2800	3300	4500
Voltage options	460/230/208			

[a] Other conditions available—see IADR performance model.
[b] Sample performance only; any outside air percentage can be used.
[c] Performance shown based on maximum compressor size.
[d] Based on 95 dry bulb/78 wet bulb outdoor and 78 dry bulb/ 62.5 wet bulb return.
[e] Humidity/dewpoint with 50% flow through dehumidification wheel.
[f] Supplementary electric heat available.
[g] Regeneration energy is variable; maximum shown.
[h] Does not include optional ERV wheel module.

Fig. 14. Initial technical specification sheet for the IADR systems based upon test data.

As shown by the final dimensions indicated for the IADR systems, one of the most important objectives, system size, was effectively met by the final system layout. The dimensions of the individual systems are within inches of the current size of comparable packaged equipment delivering a comparable cooling capacity. Given that the IADR contains the active desiccant wheel, regeneration section, and numerous control enhancements, this was a major accomplishment for this program.

The capacity data provided by Figure 14 are presented in a manner consistent with that used by the literature of the major HVAC suppliers of rooftop packaged systems. Given the increased flexibility of the IADR systems versus conventional equipment, performance tables can address only a small portion of the overall operating map because the outdoor air quantities, amount of bypass, and compressor capacity can all be modulated. In addition, since the IADR can be applied as either a total conditioning system or as a DOAS, at least two product catalogues would ultimately be required to provide a comprehensive performance map for these systems.

Fortunately, few designers rely upon the catalogue information for selecting equipment; the vast majority are opting for a computer selection program that allows the user to define the necessary input conditions and supply conditions required. The most beneficial software package would be one that allows the user to complete the building loads; determine if the use of an IADR system is merited; and, if so, compare the advantages offered against those provided by conventional packaged equipment. This software package would be the next logical step toward successful commercialization and marketing of this technology.

Coincident with the challenges posed by the unit size and panel construction (packaging), the major subcomponents required development, testing, and optimization. The issues included active desiccant wheel performance, variable-speed compressor operation, and development of the regeneration burner section.

5.2 Active Desiccant Wheel Analysis and Optimization

UIC participated in the product development program by analyzing and optimizing the performance of the active desiccant wheel. The SEMCO manufacturing process for its active desiccant wheel provides a cost-effective end product with an extremely low pressure loss relative to other technologies. It uses a novel zeolite composite that offers some interesting performance advantages, including the ability to effectively cosorb a high percentage of both indoor and outdoor contaminants. This advantage was reported in Fischer et al. 2002.

Single blow tests conducted by UIC confirmed that the desiccant wheel performed as intended and that the novel zeolite mix showed a high moisture adsorption capacity relative to the amount of desiccant included within the desiccant wheel matrix. Figure 15 is a sample of the output from one of the UIC single blow tests on the SEMCO matrix.

The primary disadvantage associated with this manufacturing approach is that the aluminum matrix, while it did not significantly deter the ability of the wheel to dehumidify, did carry over more heat from the regeneration air stream to the supply air stream. The carry-over is not problematic if a secondary sensible wheel is positioned in the system to recover this heat to pretreat the regeneration air stream. However, since the air leaving the active desiccant wheel within the IADR is mixed directly with the air that leaves the cooling coil and bypasses the active desiccant wheel, any unnecessary carry-over heat somewhat limits the net sensible capacity offered by the IADR.

As part of the optimization program, active desiccant wheels that used a non-aluminum substrate were built, analyzed, and tested in the SEMCO air test laboratory with mixed results. However, the fiber-based wheel with the best performance was found to provide both the moisture capacity desired and less heat carry-over.

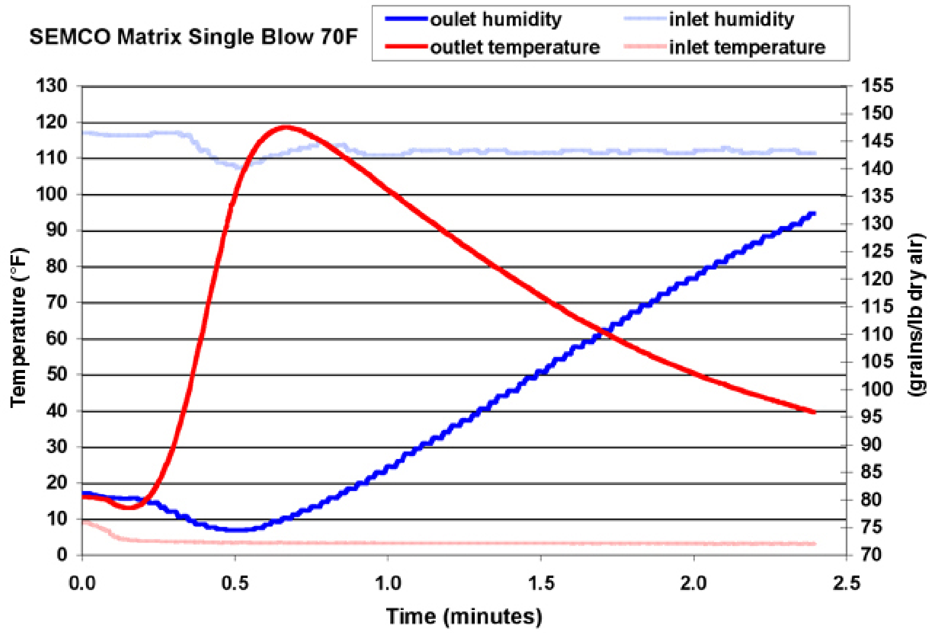


Fig. 15. Example of UIC single blow test data used for desiccant wheel optimization.

The testing completed by UIC suggests that perhaps the best-performing wheel overall would be one combining the low-mass, fiber-based substrate with the novel zeolite composite currently used by the SEMCO wheel. The potential for enhanced overall system performance justifies recommending this development program for future work. Both the fiber-based active desiccant wheel and the aluminum-based wheel will be field tested to determine if the increased sensible capacity offered by the fiber-based wheel justifies the added manufacturing cost.

5.3 DX Cooling Capacity Control and Efficiency Enhancement

Early in this R&D effort, it became apparent that controlling the capacity of the vapor-compression equipment could result in significant performance improvement. After a number of options were investigated, the solution chosen resulted in a major enhancement to currently available packaged equipment. The refrigeration section included in the IADR now uses variable-speed compressors, extended surface area evaporator and condenser coils, thermal expansion valves, high-capacity condenser fans, and numerous other features that allow the system to condition variable outdoor air fractions and inlet conditions.

As shown in Table 3, many common applications now require low-dewpoint air to effectively control indoor humidity levels. The IADR is able to deliver these very dry conditions by using the strength of the active desiccant technology rather than requiring very low temperatures leaving the evaporator coil. This is advantageous for several reasons. First, as shown in Table 3, it requires far less refrigeration capacity than conventional cooling approaches. Second, since the IADR requires a more moderate evaporator leaving coil temperature and therefore can operate at higher suction pressures, the vapor-compression refrigerant cycle is more efficient. As shown in Figure 16, the net cooling output from an Air-Conditioning and Refrigeration Institute–rated compressor drops significantly as the air temperature leaving the evaporator coil (suction pressure) decreases.

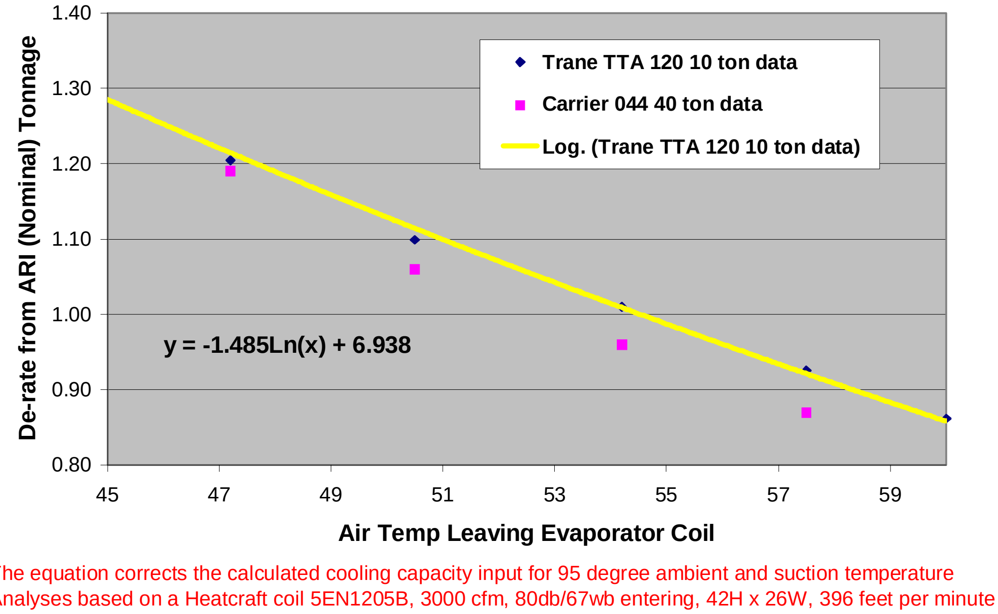


Fig. 16. Impact of lower leaving coil air temperature on compressor efficiency.

The capability of the IADR to function, for a given application, with a 56ºF (13.3ºC) leaving coil temperature, while a more conventional system providing the same supply air dewpoint requires a 50ºF (10ºC) dewpoint, increases its operating efficiency by approximately 15%. This is in addition to the energy saved by reducing the overall number of tons required and by transferring part of the dehumidification load onto the less expensive natural gas.

5.4 Regeneration and Parasitic Energy Optimization

Two important optimization issues needed to be addressed with regard to the regeneration section of the IADR. The first involved the selection of the burner itself and the associated controls. The second, equally important, was minimizing the parasitic energy (pressure loss and fan horsepower) associated with the regeneration side of the active desiccant wheel.

Numerous innovations were made with regard to the direct-fired gas burner that has been integrated into the IADR. The construction details for this burner are beyond the scope of this report. However, one of the most important developments was the ability to match readily available, cost-effective safety components with a burner type that has not previously been used in the HVAC industry. The result was a very flexible, effective, and cost-efficient regeneration section.

One of the appropriate market objections to past active desiccant systems was the large parasitic energy loss associated with the pressure drop across both sides of the desiccant wheel. This is particularly true for the regeneration air stream, where the elevated temperatures result in high air pressure losses. The IADR approach has effectively addressed this issue by significantly reducing the pressure loss across the active desiccant wheel. On the supply side, a typical pressure loss is in the range of 0.2 to 0.4 in. wg. This is well below the loss associated with a loaded 30%-efficient air filter, resulting in an insignificant energy impact. In fact, this pressure increase is essentially offset by the anticipated increase in pressure across the evaporator coil that would be experienced by a conventional system operating at colder leaving air temperatures, and seeing more condensate, in an attempt to reach a similar supply air dewpoint.

The active desiccant wheel in the IADR processes only a fraction of the supply air stream, and the regeneration airflow is approximately half of that amount; therefore, the amount of regeneration flow is quite small relative to the supply airflow (typically 20%). Since this regeneration flow is only passed across the regeneration side of the active desiccant wheel and a direct-gas-fired burner, the fan energy used for regeneration is modest. For example, an IADR 4500 operated as a DOAS and delivering 4000 cfm of outdoor air at a 48ºF (8.9ºC) dewpoint will use only 800 cfm of regeneration airflow, consuming less than one horsepower.

Because the IADR system positions the active desiccant wheel after the cooling coil, sized to handle only a fraction of the total supply air flow, the desiccant wheel processes cool, saturated air, thereby optimizing the dehumidification efficiency. As a result, the desiccant wheel can use either large corrugations for the matrix or be designed with a reduced thickness in the direction of airflow while still delivering the desired dehumidification effectiveness. In addition, moderate regeneration temperatures can be employed (170 to 210ºF). The combination of these two design advantages results in much lower pressure losses than the 1 to 1.5 in. wg losses typically experienced by other active desiccant systems.

5.5 Accommodating Waste Heat for Regeneration (CHP Integration)

One of the objectives for this program was to develop an integrated, active desiccant hybrid system that could make effective use of waste heat rejected from power generating equipment such as internal combustion engines and microturbines. The challenge was to design a system that would effectively use the moderate hot water regeneration temperatures of 170 to 190ºF (76.7 to 87.8ºC) associated with internal combustion engines or microturbine heat recovery units. The other challenge was to match the regeneration needs with the available energy output. The IADR addresses both of these challenges by making good use of moderate, low-quality regeneration energy and by requiring a relatively small amount of energy input per ton of latent cooling delivered. The IADR is therefore an excellent technology match for CHP systems.

6. FULL-SCALE SYSTEM LABORATORY TESTING

6.1 Test Procedure

A key deliverable for this R&D effort was a full-scale production model of an IADR system. An IADR 3000 was constructed and installed within SEMCO's engineering test laboratory (Fig. 17). It was fully instrumented and integrated with the main laboratory DDC and data acquisition system. Nearly every possible refrigeration and dehumidification state-point was monitored.

Two large preconditioning systems within the test laboratory were used to create a wide range of simulated outdoor air and return air conditions, carefully controlled by the central DDC system. By modulating the following control parameters, the performance capability of this system was established:

- The speed of the compressor was modulated to vary cooling output.
- The position of the bypass damper was modulated to vary the bypass percentage of the supply around the active desiccant wheel.
- The speed of the supply air fan was varied to modulate airflow.
- The regeneration air temperature was modulated.
- The speed of the desiccant wheel was modulated for dehumidification optimization.
- The condensing fan airflow was modulated to control the condensing temperature.
- The return air and outdoor air dampers were modulated to vary the outdoor air percentage.

Fig. 17. IADR 3000 prototype installed and tested in SEMCO air laboratory.

The IADR system was fully instrumented to measure and trend all of the various temperature and humidity conditions throughout the IADR system. All aspects of the refrigeration circuit were also instrumented and trended. The three frequency inverters on the compressor, evaporator fan, and supply air fan were also monitored via the DDC system, providing information ranging from frequency to amp draw.

Figure 18 provides a sample screen from the DDC system, customized for the IADR system tested as part of this effort. All of the state-points shown on this figure were monitored and reported during each test. Numerous other state-points not shown on the screen could also be trended and reported as desired. The data shown reflect a test completed with the bypass damper totally closed to demonstrate the low-dewpoint drying capability offered by the IADR approach. This type of performance would be typical of a recirculated, unoccupied mode of IADR operation, beneficial to many facilities such as schools and movie theaters.

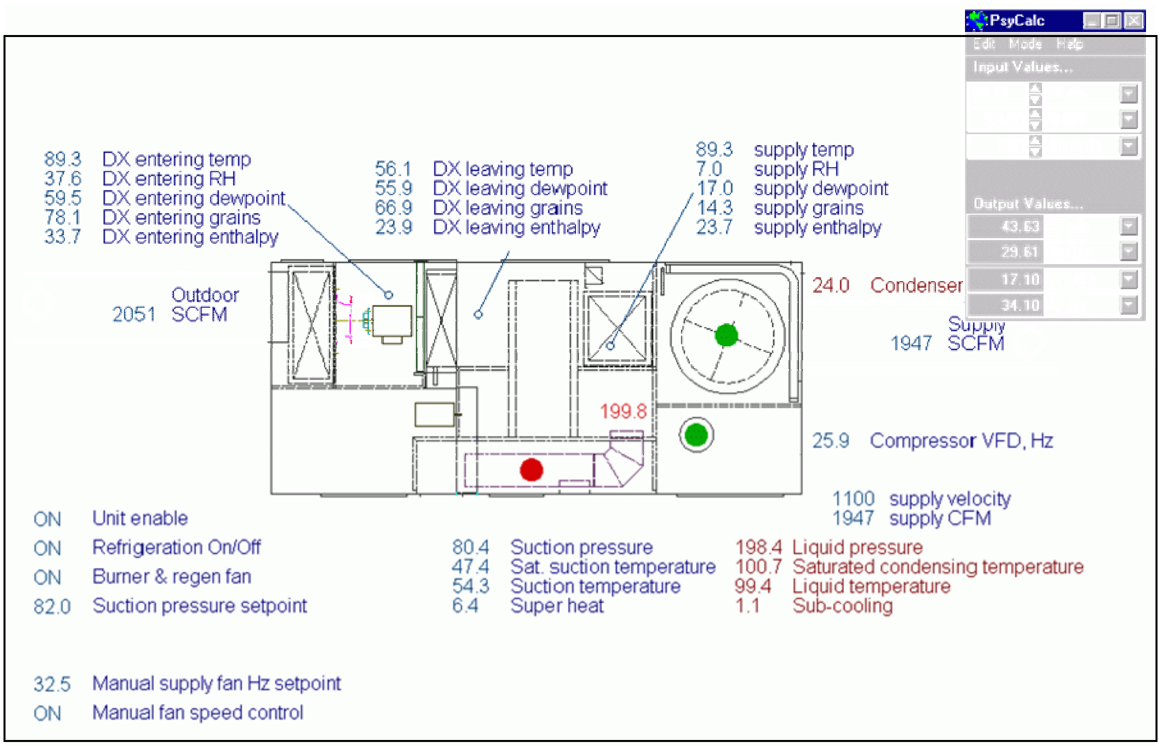


Fig. 18. Example of the data acquisition screen used for IADR testing.

6.2 Summary of Results

The cooling-dehumidification performance envelope provided by Figure 14 attempts to summarize the range of test data obtained as a result of this R&D effort. As shown, the data are presented to reflect two different outdoor air percentages, 100% and 30%, and two different flow rates, nominal and maximum. The resulting supply air temperature and humidity conditions are given in delivered sensible and latent cooling capacities, consistent with those of commercially available packaged equipment. However, what represents a significant departure from conventional performance is (1) the wide range of delivered humidity levels possible, (2) the net dehumidification load possible with the IADR, and (3) the wide range of sensible heat ratio performance obtainable.

The flexibility of delivered air conditions and decoupling of the delivered dry bulb temperature from the dewpoint condition (absolute humidity) are beneficial because they allow the system to match the space loads that exist in many buildings, as shown in Table 3. This is especially true for buildings of the future designed to include high-efficiency lighting as required by ASHRAE 90.1. Using current conventional systems to condition such facilities, especially those requiring high outdoor air percentages, will result in very short cycle times, poor humidity control, and potential frosting problems at part-load conditions.

The control system flexibility of the IADR makes possible a wide spectrum of potential supply air conditions; therefore, providing a comprehensive performance map for this final report is not practical. Essentially any reasonable supply air condition can be provided. The only variables would be the amount of refrigeration precooling provided, the amount of supply air delivered to the active desiccant wheel, and the amount of regeneration energy available. Figure 19 shows measured performance for the IADR as applied to a typical retail facility in a total conditioning approach.

A sampling of typical supply air conditions has also been provided previously in Fischer and Sand 2002. The integrated hybrid version (the IADR) offers a significantly larger scope of potential supply air conditions because it offers improved refrigeration performance, control options, and operational flexibility compared with the conventional packaged equipment targeted for use with the add-on active desiccant module.

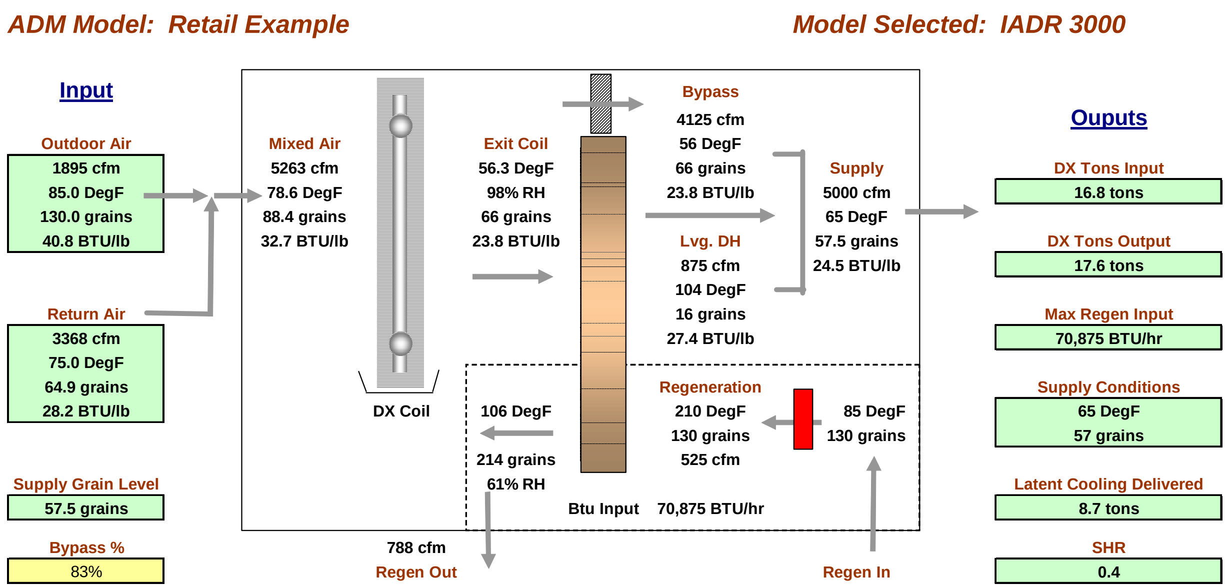


Fig. 19. Typical performance of the IADR operated as a total conditioning system.

7. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The deep drying dehumidification capability associated with an active desiccant wheel was successfully combined with an advanced vapor compression cooling system, using variable-speed capacity control, to create a compact, energy-efficient hybrid HVAC system. The system was specifically designed to be applied as a DOAS or as a total conditioning system. The system can be operated with a constant volume airflow or variable-volume airflow delivery as a result of its inherent capacity control.

The system was developed to offer a simple substitute for conventional rooftop equipment. It looks similar to RTUs in construction, fits a similar footprint, and is selected and specified in a similar manner. It can be operated without a return air path or can use an optional total energy recovery module to increase the overall system efficiency.

Most important, it can process any outdoor air percentage and deliver essentially any sensible heat ratio needed to maintain a desired space temperature and humidity level. Thus it meets a strong market-driven need, providing a system that can accommodate the increased, continuous outdoor air quantities required by ASHRAE Standard 62 without creating uncomfortably humid conditions in ventilated spaces.

This IADR system also allows the delivery of the supply air at the desired supply air temperature and at a separate, much lower dewpoint temperature without the use of the currently used over-cool and reheat approach, now prohibited by ASHRAE Standard 90.1. Increased lighting efficiencies required by 90.1 will drive designers to raise supply air dry bulb temperatures, but supply dewpoints will have to remain low in order to meet the desired space humidity levels.

Because it uses relatively high suction pressures to deliver low-dewpoint air, the refrigeration side of this hybrid system is far more energy-efficient than conventional cooling systems providing a similar latent capacity. By completing much of the dehumidification with lower-cost natural gas (at traditional gas and electricity prices), it reduces the energy cost paid by the end user and the net impact on the environment of electricity generated from fossil fuels. Positioning the active desiccant wheel after the precooling coil reduces the size of the wheel as well as the pressure loss and regeneration airflow, resulting in minimal parasitic energy losses and a substantial improvement over previous commercially available active desiccant systems.

Based on the positive performance results obtained in full-scale laboratory testing, several IADR systems are either installed or soon will be installed at various demonstration sites. The systems will be equipped with remote, real-time data acquisition equipment.

Future work is needed in the following areas before full-scale commercialization.

Heating Season Heat Pump Integration

To be a direct replacement for a conventional RTU, the IADR must provide an efficient yet flexible heating mode; otherwise, its full potential would not be realized. The base design for the cooling/dehumidification performance includes extended surface area evaporator and condensing coils, a variable-speed compressor, and a DDC system. As a result, integrating a heat pump cycle to this system would provide the needed energy-efficient heating mode. It would also offer an added advantage over current heat pump systems that would resolve the primary weakness associated with the technology. Heat pumps work efficiently at moderate outdoor air temperatures, but in periods of extremely cold weather, many heat pumps do not have the capacity to effectively warm the space. As a result, many designers opt for inefficient but flexible electric resistance heating.

During such periods, the IADR can easily energize the regeneration heater and increase the speed of the active desiccant wheel, changing it from a dehumidification device into a highly efficient heat exchanger. This allows the supply air stream to be heated further, as necessary, at times when the heat pump performance is less than required.

The additional work needed to integrate the heat pump capability is modest compared with the development work required to optimize the cooling/dehumidification side.

Performance Modeling

The IADR can be applied in numerous ways. For the first time, designers can match the sensible and latent loads, at any point in time, with the supply air condition (temperature and humidity) that is needed to condition the space. The IADR offers so much flexibility that it is impossible to provide all the performance data in the traditional, tabular format available for most conventional rooftop systems.

As a result, prior to commercialization, a performance tool must be developed to aid the designer in the selection process and performance mapping. This program will have to be user-friendly, flexible, and fast to induce a majority of consulting engineers to use it frequently. Early market research suggested that most engineers will use the technology if it is easy to use, is easy to specify, and solves the problems presented by ASHRAE 62 compliance. It will be especially beneficial if the same or a similar computer model would guide the engineering community through a simple load calculation to determine the required sensible and latent load ratios. If the loads cannot be handled by a conventional system without resulting in extended periods of unacceptable space humidity, then the advantages offered by the IADR approach would become apparent.

Continued Active Desiccant Wheel Development

Further product development and optimization of the active desiccant wheel will have to be completed to fully integrate the findings offered by the UIC research. The optimum end product would minimize heat carryover while offering the maximum dehumidification capacity and the ability to remove a high percentage of indoor and outdoor air contaminants. Simply put, it would combine the strengths of the composite zeolite used by the current SEMCO wheel with a fibrous substrate wheel.

Continued Development of Controls

The unlimited capability provided by the integrated DDC system integral to the IADR will need to be refined as more application types are considered. Field data will provide feedback that will be used to optimize the refrigeration cycle efficiency, true economizer operation, humidity control options, and numerous other factors influencing the indoor environment and cost of operation. Controls optimization will be an on-going requirement.

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